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SYRACUSE, NEW YORK

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Sonar Technical
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HYBRID PROCESSING TECHNIQUES FOR ACTIVE SONAR .

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Naval Ships Systems Command
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SECTION I
INTRODUCTION

Hybrid signal processing techniques, which combine both coherent and non-coherent operations, have been under development for active sonar applications for several years by the General Electric Company. The hybrid approach to sonar signal processing offers several important advantages over the more conventional, fully-coherent techniques. A particular hybrid processing technique developed by the General Electric Company which has many user benefits is identified by the acronym MEDIOR. This technique has been tested against actual sea data and the advantages claimed for the system have been confirmed. This proposal describes the MEDIOR system in its current format (Section II), proposes certain exploratory development items for which Navy-funding support is being requested (Section III), and outlines the proposed schedule and reports (Section IV).

SECTION II
MEDIOR SYSTEM

In its most basic form, the MEDIOR System comprises a MEDIOR waveform and hybrid processor as depicted by the diagrams of Figure 1.

A. TRANSMIT WAVEFORM

The MEDIOR transmit burst is comprised of a series of subpulses distributed in the frequency-time plane so as to enhance both noise and reverberation performance. The subpulse concept arises from the realization that frequency and time spreading effects encountered in the medium will place a practical upper limit on both the duration and the bandwidth of the transmitted pulse (insofar as these items relate to coherent processing operations to be done in the receiver). Studies have indicated that approximate practical limits (hull-mounted, long-range operation) on coherent pulse length and bandwidth are 100 milliseconds and 10 Hz, respectively. Thus a medium-matched pulse under such conditions would be a simple CW pulse of approximately 100 milliseconds duration.

A single pulse having the time and bandwidth restrictions described would not normally occupy the available frequency and time space allotted for transmission. A burst of basic subpulses can be employed to satisfy the space allocation and will also obtain additional detection performance by restricting the spreading losses due to medium effects. A possible transmit burst frequency-time pattern is indicated by Figure 1a.

B. PROCESSING TECHNIQUE

A hybrid processor suitable for receiving the transmit burst is shown in simplified form in Figure 1b. The input signal first enters a series of level compensation amplifiers, a_k, which in turn feed a bank of filters, H_k. Each filter of this bank may be assumed to be essentially matched to a subpulse at a given center frequency. The filters in the bank of Figure 1b are identical except for design center frequency. Following the filter bank, a detector operation is indicated which represents the beginning of the non-coherent processing portion of the hybrid receiver. In effect, each of the subpulses of the target echo are filtered and detected independently.

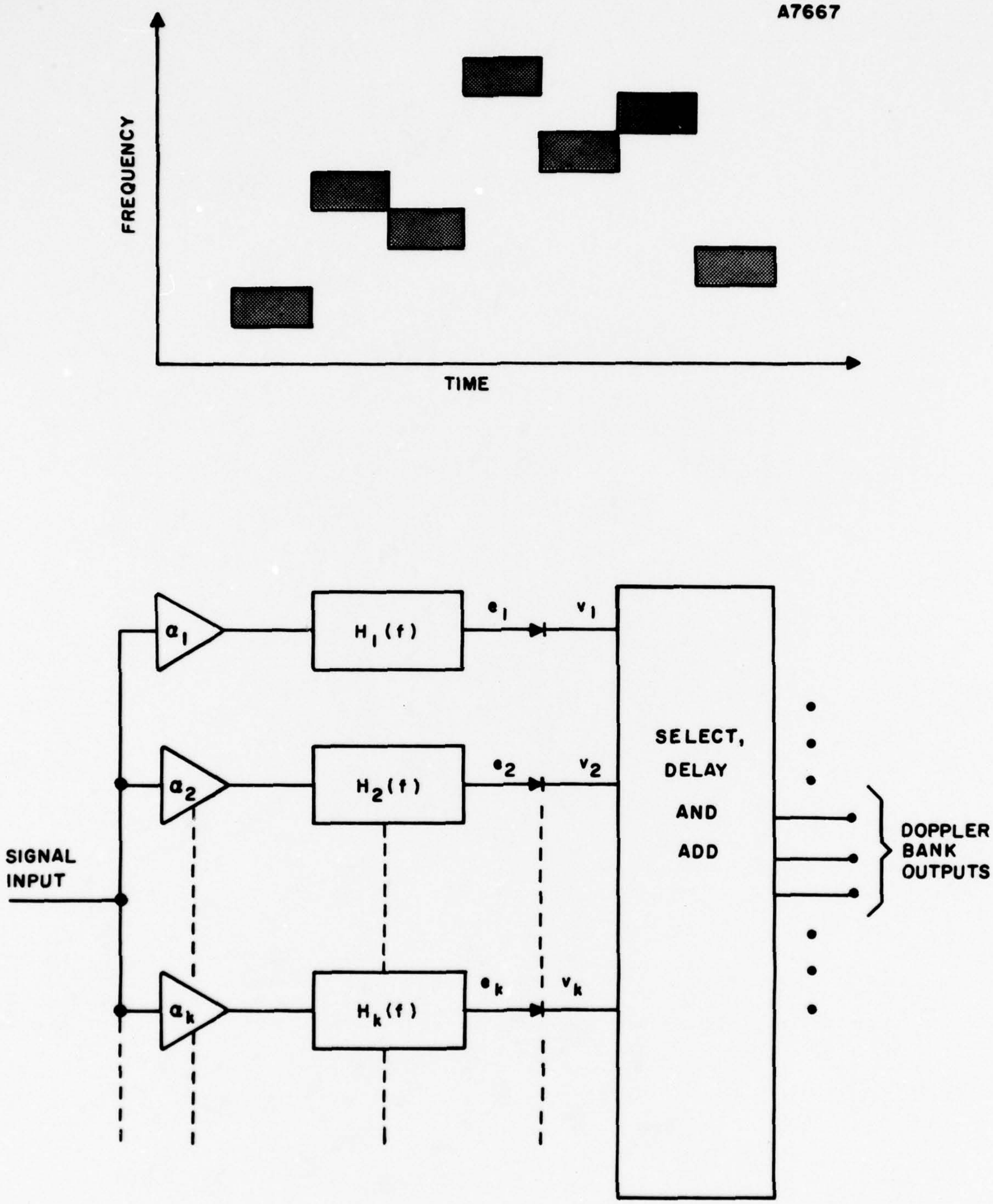

Figure 1. MEDIOR Waveform & Hybrid Processor

For any assumed target doppler, a particular subset of the filter-detector output voltages, V_k, will be involved in the detection process. This selected set of output voltages are processed in an appropriate delay-and-add operation to produce a particular doppler bank output. A select, delay-and-add operation is performed on the (baseband) filter bank output voltages to produce the doppler bank output voltages as indicated in Figure 1b. The above description of the MEDIOR technique covers basic principles only. Several important additional operations must be performed in practical applications and these will be described in subsequent paragraphs.

The previous description involves a transmit waveform that is comprised of a burst of basic subpulses as shown in Figure 1a. The MEDIOR hybrid processing technique is not by any means restricted to such subpulse transmissions. The use of the MEDIOR processing technique with standard FM/CW types of transmission has demonstrated many advantages over the more conventional FM/CW reception techniques. In particular, the work done to date has involved a combination FM/CW waveform with the parameters as shown in Figure 2. An understanding of the operation of the hybrid processor with such a waveform may be obtained by assuming an equivalent subpulse structure for the actual continuous waveform. As shown in Figure 2, the FM portion of the waveform may be equivalenced to a series of basic pulses employing a staircase frequency-time pattern. The CW portion of the waveform of Figure 2 may be equivalenced to a sequence of subpulses transmitted at adjacent times on the same frequency channel. In other words, by proper rearrangement of the frequency-time pattern of the transmit burst of Figure 1a, an arrangement essentially equivalent to the actual FM/CW transmission of Figure 2 could be obtained. Thus waveforms which were intended for more conventional processing techniques may be handled by the hybrid processor technique of Figure 1b. It has further been demonstrated that many important advantages accrue from such an operation.

A practical implementation of the basic processor of Figure 1b is shown in Figure 3. This processor concept has been simulated on the GE 635 computer to process sea data with outstanding results. A "brassboard" real-time processor and display which provides the functions shown in Figure 3 is near completion. When completed, the brassboard MEDIOR processor will be used first as a laboratory real-time processor for sea tape analysis and then reconfigured for operation at sea.

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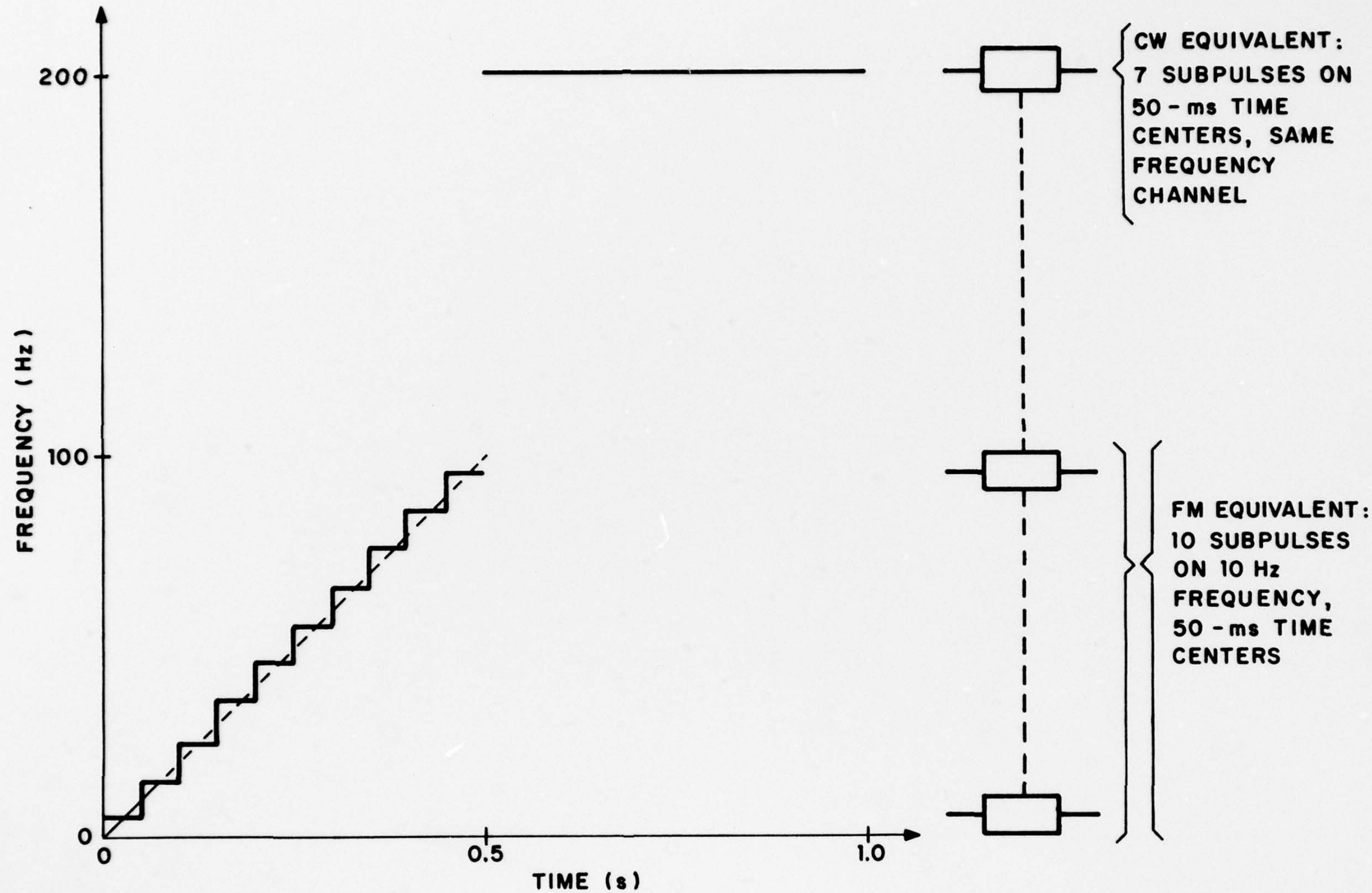
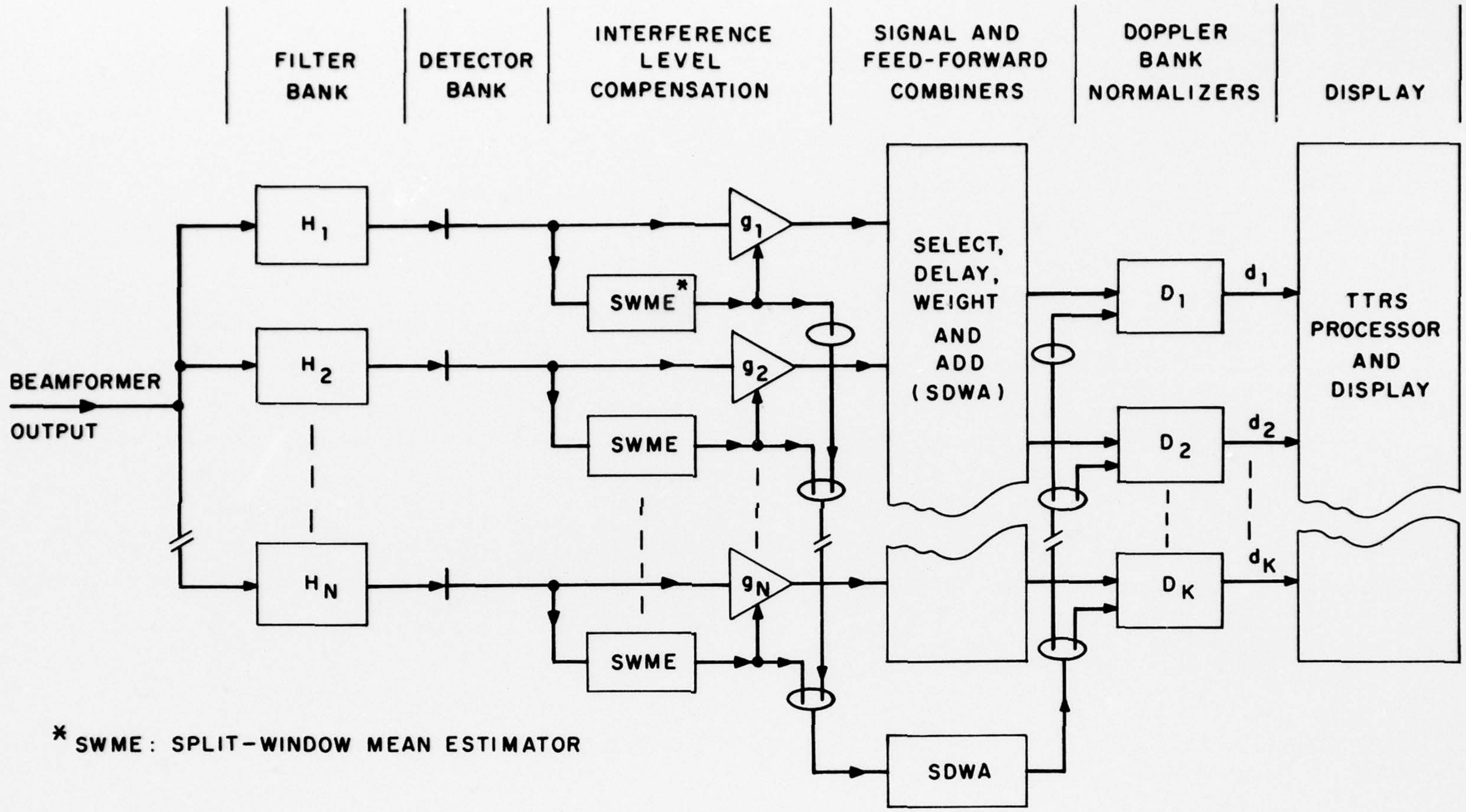


Figure 2. FM/CW Subpulse Equivalence



*SWME: SPLIT-WINDOW MEAN ESTIMATOR

DOPPLER BANK NORMALIZATION:

(A) SWME TO UNIT MEAN (NON-FEED-FORWARD)

(B) FEED-FORWARD TO UNIT MEAN

(C) FEED-FORWARD TO ZERO MEAN, UNIT VARIANCE

Figure 3. MEDIOR Signal Processor/Display Subsystem

The filter and detector banks of Figure 3 are equivalent to those shown in Figure 1b. The relative gain settings on a per-channel basis indicated by the α_k operators in Figure 1b are accomplished by the interference level compensation circuitry shown in Figure 3. A split-window mean estimator is employed in each channel to determine the local mean on a time-continuous basis. The voltage gain in each channel is then made inversely proportional to the square of the estimated mean. This operation, though unorthodox in sonar systems, is necessary for the optimum weighting of each of the filter bank channels prior to later addition for creation of the doppler bank outputs. In essence, the interference level compensation provides a relative weighting between filter bank channels such that those channels having a high signal-to-background ratio will be emphasized, while those channels having a low signal-to-background ratio will be suppressed. It should be pointed out that the interference level compensation operations do not provide normalization in the usual (constant false alarm rate) sense of this term. Normalization is accomplished at the doppler bank outputs in a rather unique way and is described in subsequent paragraphs.

The interference level compensator outputs are combined in the conventional delay-and-add fashion to produce the doppler bank outputs as described previously relative to Figure 1b. Normalization is required for the doppler bank outputs and several different schemes for accomplishing this have been tested. The most obvious method for doppler bank normalization involves the use of a split-window mean estimator in each doppler bank output line to bring each such line signal background to the same mean value. This technique has been found to be acceptable when processing waveforms such as the FM portion of the combination waveform of Figure 2.

C. NORMALIZATION TECHNIQUE

The normalization requirements, when waveforms such as the CW waveform of Figure 2 are employed, are much more severe and the split-window mean estimator, as a doppler bank normalizer, has definite drawbacks when such waveforms are considered. A normalizing technique which has been found to be very effective when difficult waveforms such as long-pulse CW are employed will now be described. This "feed-forward" technique capitalizes on the mean-estimate statistics that were gathered

in the interference level compensation operation following the filter/detector operation. The running estimates of background mean value (which are made originally for interference level compensation) are retained on a per-channel basis in memory arrays. Since the logic of the delay-and-add operation which produces the doppler bank outputs is known, a similar logic operation on the stored mean estimates can be used in a feed-forward manner to produce an estimate of both the mean and variance for each doppler bank output as a function of time. By this technique, the doppler bank outputs can be normalized to unit mean or to zero mean and unit variance, as desired. Both techniques have been used extensively with the zero mean and unit variance indicating a slight advantage over the feed-forward normalization to unit mean only. Both feed-forward normalization techniques have proven to be extremely effective when used with the FM/CW waveform of Figure 2, especially for intermediate doppler values of the order of three knots. In this particular target doppler region, prior-art techniques currently in use appear unable to capitalize on the inherent detection capability of the waveform employed.

D. DISPLAY TECHNIQUE

A display technique developed by the General Electric Company for use with the MEDIOR processor will now be described. The basic principles of the target track recognition system (TTRS) are shown in Figures 4 and 5. As shown in Figure 4, the doppler bank output is scanned in each range cell interval for a greatest-of selection. This selection is tested against a threshold and if this test fails, no action is taken for this particular range cell. If the greatest-of selection exceeds the threshold, a display word is generated and stored which contains range, doppler, and level information. The display words in memory are utilized by the display subsystem to produce a modified B-scan type of ping history display as shown in Figure 5. The display word is examined and a mark is made on the ping history display at a location determined by the range index information and intensity controlled by the level index information. The mark created is a straight line whose slope is a function of the doppler index information. Parameters are arranged such that the end points of each line thus drawn represent extrapolations of the position occupied by the target one-half ping period before and after the particular range cell time. Therefore if an actual target is present, the end points of these individual lines will connect from ping to ping and a

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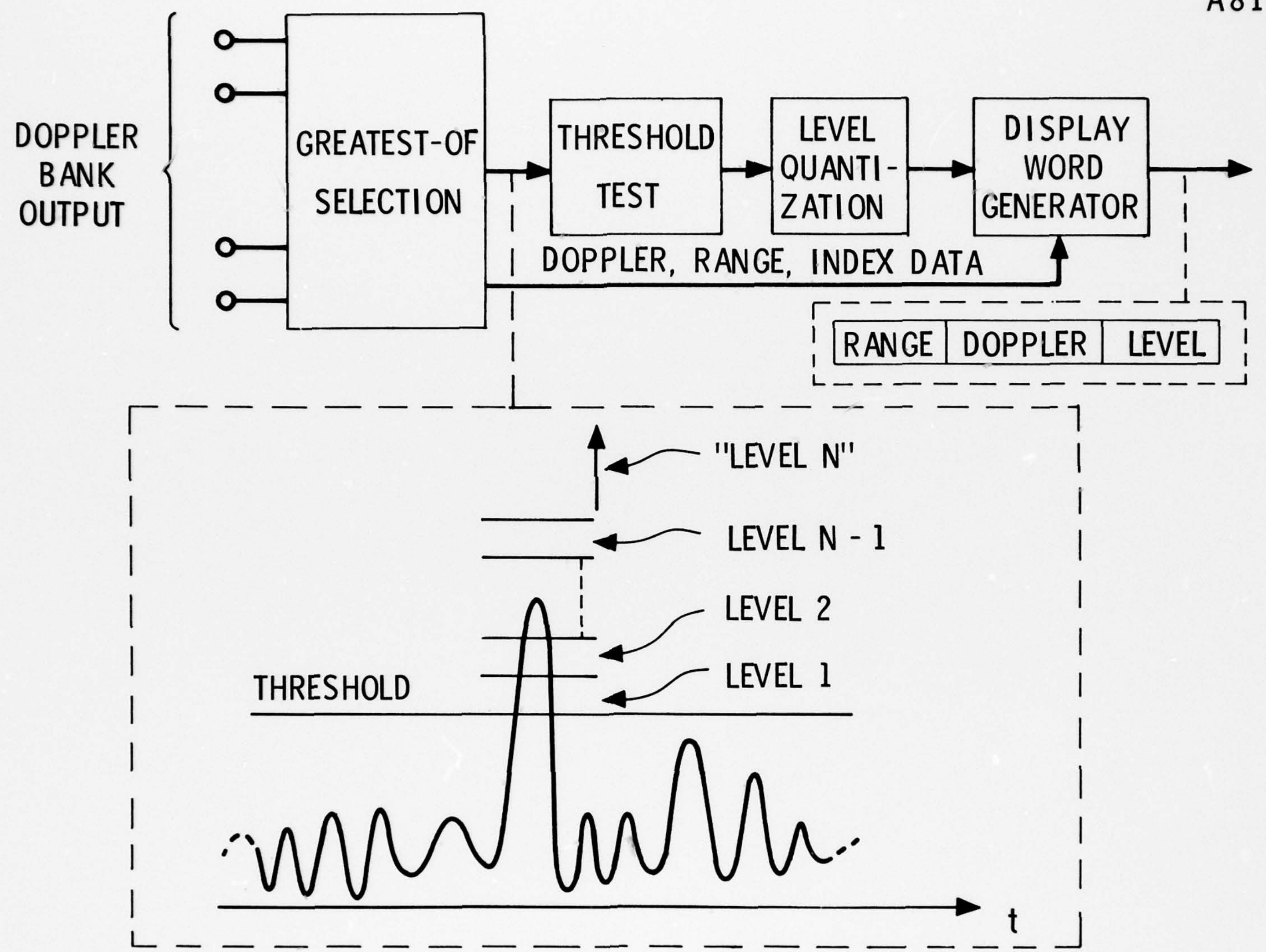

Figure 4. Target Track Recognition System (TTRS) Preprocessor

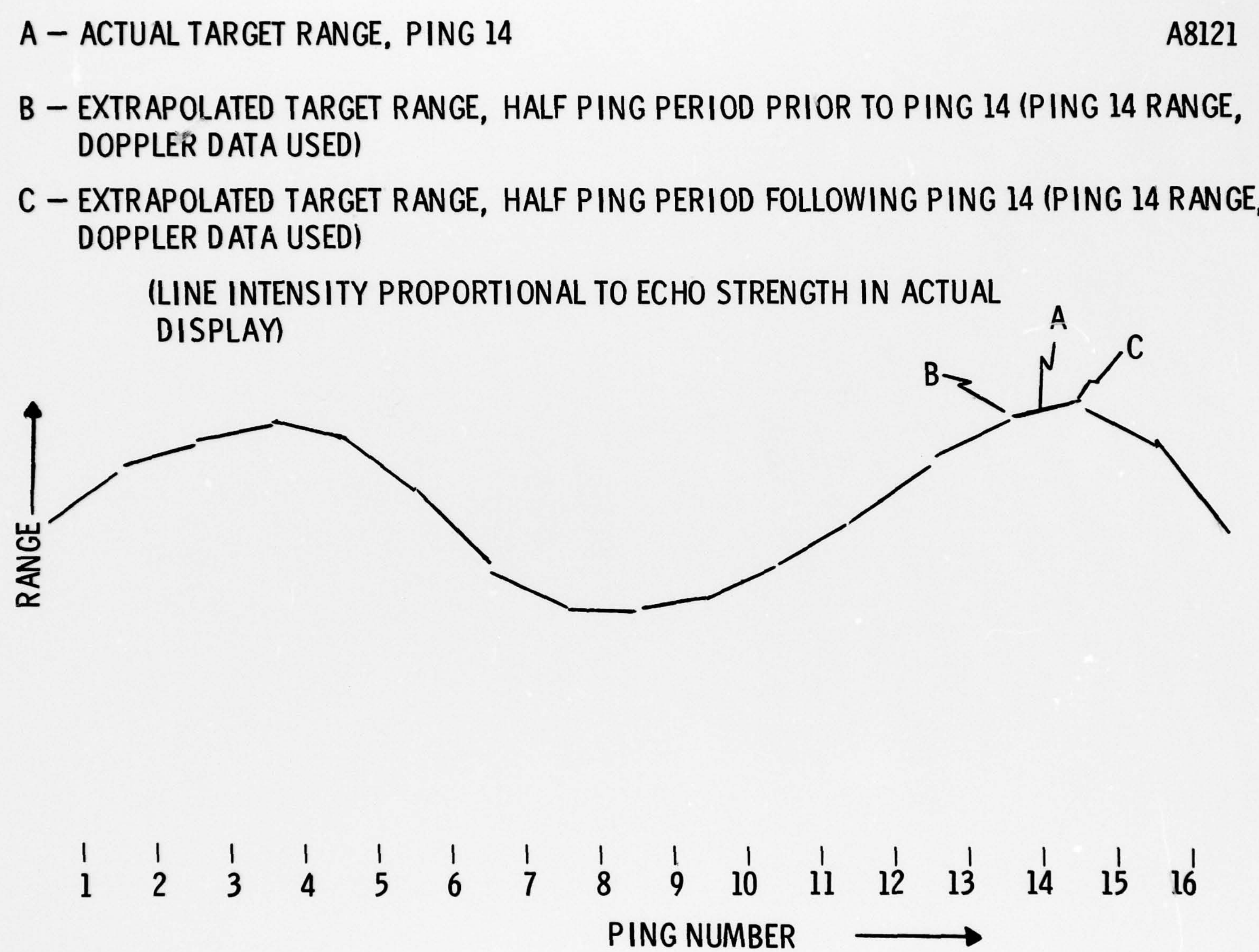

Figure 5. Target Track Recognition System (TTRS) Display Format

simulation of the target track will be presented to the operator. It has been found that this type of display, which introduces doppler information in addition to the normal range and amplitude information, offers many advantages to the operator for the recognition of target tracks.

E. SUMMARY

The MEDIOR processor and display system described above has been simulated on the GE 635 computer and much actual sea data from the AN/SQS-26 sonar system has been processed thereby. Results, when compared to conventional processing and display techniques, have indicated many major advantages for the MEDIOR approach. The MEDIOR brassboard processor and display system will soon be available for final verification of both the advantages and practical, low-risk nature of the above-described system. In the course of the development of the MEDIOR techniques, several points of interest and possibilities for futher analysis and improvement have evolved which are of an exploratory development nature. Some of the more important of these items are listed and described in the following section. Navy support for this work is being sought by this proposal.

SECTION III
EXPLORATORY DEVELOPMENT ITEMS

A. NORMALIZATION STUDY

Normalization techniques have too often been ignored by systems planners or relegated to a "minor detail" category. In reality, the normalization problem is one that demands early and continuous attention in sonar systems planning. Anyone who has worked with sonar systems at sea or with sonar data recorded under actual operating conditions realizes that, without proper normalization, very serious performance limitations will have to be accepted.

In the MEDIOR system of Figure 3, the feed-forward normalization techniques (and its relationship to the interference level compensation operation) account for much of the improved performance of this system relative to prior-art approaches. This is believed to be especially true in the case of intermediate to low target doppler values. Many of the difficulties of conventional processing techniques can be traced to a shortcoming in the normalization approach taken. The system of Figure 3 uses a rather unique approach to obtain accurate normalizing information in both the frequency and time dimensions. The interference encountered in a typical ping cycle varies markedly in both spectral distribution and level as a function of time. The interference spectrum is highly non-uniform in certain parts of the ping cycle due to the high relative content of reverberation energy. In other parts of the ping cycle, the reverberation levels are much lower and a more nearly uniform spectral distribution of interference results. The system of Figure 3 accommodates this difficult situation by first using the filter bank to obtain a separation in the frequency domain. Following this, the split-window mean estimators are used on a per-channel basis to obtain background data along the time dimension.

It has been shown by the reduction of a variety of sea data that the normalizing techniques included in Figure 3 are extremely effective. However, further studies of this and associated techniques are warranted to obtain a deeper understanding of the normalization problem which could possibly lead to yet further improvements in the basic techniques of Figure 3. Specifically, an investigation of the normalizing

parameters would be very useful. In our past work, the system of Figure 3 was simulated on the GE 635 computer and cost considerations prevented any real experimentation with the window and gap sizes employed in the split-window mean estimators. It was found that half-second windows and a half-second gap seem to give a satisfactory level of performance. However very little experimentation was done with parameter variations. The early availability of the MEDIOR brassboard will enable such parameter investigations to be carried out quickly and at a low cost.

For the most part, visual observation of the TTRS displays has been used to evaluate the relative merits of a few normalizing parameter sets and the particular type of feed-forward normalization. For example, very little difference was seen between the feed-forward normalization to unit mean and the feed-forward normalization to zero mean and unit variance. The latter approach seems to be somewhat better but no quantitative results are available to support this conclusion. It is clear that more serious studies of the statistics of the doppler bank outputs are required to determine whether the feed-forward normalization to zero mean and unit variance is worth the extra complexity as compared to the simple feed-forward to unit mean. In addition, some statistical differences between the different doppler bank outputs are expected and a study of output statistics could lead to means for obtaining performance improvements for a minimal additional system investment.

Further study of Figure 4 reveals that the TTRS display technique requires precise normalization of the doppler bank outputs by virtue of the fact that a greatest-of selection is made in each range cell as a prelude to the creation of the display word If the normalization were not proper at the doppler bank output, the final display results would indicate this failure rather quickly. Thus it is fairly certain that a very close control of doppler bank output statistics is being obtained with the present system. Because of the excellent normalization, it does not seem likely that an extended MEDIOR system involving the display of multibeam outputs would pose any severe or unexpected problems. However, this assumption should be verified to assure that the normalization technique which finally evolves is adequate to insure proper operation in the multibeam case.

B. WAVEFORM DESIGN STUDY

An arbitrary separation of target doppler into "low" and "high" ranges appears to be unnecessarily restrictive and can, in fact, lead to systems with performance deficiencies in the doppler crossover region. A more general approach to the problem of target doppler has been taken in recent studies[1] by the General Electric Company and a measure of system performance as a continuous function of target doppler values has been established. It has been shown in Reference 1 that the performance curve as a function of target doppler can be shaped within reasonable limits by proper choice of the transmit waveform. It has further been shown that the available transmit bandwidth and transmit time are important system resources that can be optimized with respect to the particular tactical situation being considered.

The relationships between available transmit bandwidth and system performance as a function of target doppler appear to be especially meaningful when there is a mutual interference problem. It has been shown that system performance may be improved in a very general sense as a function of target doppler by increasing the available system bandwidth. Since frequency-division techniques are a proven method for controlling mutual interference, available system bandwidth is a prime resource which must be used in the most efficient manner possible to enhance mutual-interference immunity.

One of the prmary missions of the sea trip of July 1970 is the field-testing of various waveform designs which study results indicate would be useful in certain important tactical situations. It is intended that recordings be made at sea during this trip using the standard FM/CW waveform alternating with one of the special MEDIOR waveforms. An analysis of the resulting sea tapes (both on the GE 635 computer and on the MEDIOR brassboard when it becomes available later this year) should result in a practical confirmation of the theoretical advantages indicated for these special waveforms. The results of this effort should lead to the availability of a waveform set which would permit, by selection, the optimization of system performance under various search and track situations. Performance optimization under bandwidth constraints imposed by the mutual interference problem is also an important goal.

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[1] Costas, JP, "Time-Frequency Allocation Techniques for Active Sonar," TIS No. R70EMH13, February, 1970, GE Class 2, Government unclassified.

C. DOPPLER BANK INTERPOLATION STUDY

In the MEDIOR system of Figure 3, the minimum frequency step between adjacent doppler bank outputs is normally equal to the frequency increment of the filter bank. Since the filter bank represents a significant cost item in the system (whether it is done by analog or digital means), a tradeoff must usually be made between filter bank cost, doppler coverage, and doppler increment. In order to prevent performance loss for those doppler frequencies falling in the cross-over region of the filter bank, a fairly close frequency spacing between adjacent filters of the bank is often employed. Thus, in a sense, over-sampling in frequency is employed to prevent performance degradation at intermediate doppler values.

Certain interpolation techniques have been studied which indicate means for minimizing the cross-over loss for a given frequency spacing and filter shape. This is an important area for study because the results of such investigations could lead to significant savings in the filter bank operation for a given set of requirements for the cross-over loss. The study further indicates that the interpolation operation can take place at the doppler bank output. That is, a relatively wide filter bank spacing may be used which results initially in a relatively wide spacing in the doppler bank outputs. By various interpolation techniques, intermediate doppler values can be synthesized from the basic doppler outputs, thus keeping the cross-over loss low without the need for a finer filter bank mesh. It is proposed that the present studies be continued and that the results be verified by simulation, first on the GE 635 computer. If this simulation shows favorable results, this interpolation technique would be incorporated into the MEDIOR brassboard by suitable control program changes.

D. DISPLAY TECHNIQUES STUDY

In most operational situations, multiple receive beams must be processed and the processor outputs suitably displayed. A host of possibilities for the man-machine interface are available and some of the more promising approaches should be identified and evaluated. The availability of computer-driven displays and recall from digital memory banks make possible many different approaches to this problem. For example, beams in a sector of interest could be displayed sequentially in a TTRS format for quick operator evaluation. The operator would allow the sequencing to continue if a

track were not evident. If a track became evident on one or more beam displays, then operator over-ride could be provided in the display subsystem for more careful evaulation of the area of interest. It is believed that the pattern-recognition advantages offered by the TTRS display, combined with good normalization, would aid the operator in the evaluation process that he would have to perform under such a system.

An alternate approach might involve the simultaneous presentation of a number of beams for operator viewing. Combinations of the above techniques could also be used such as a sequential display of three adjacent beams.

In addition to the multiple-beam problem discussed above, several interesting questions could be addressed relative to the basic TTRS display concept. These questions involve the effects of such items as false-alarm rate, amplitude quantization, doppler quantization, and range quantization. For example, it may be possible to severely limit the amount of detailed information concerning amplitude, range, and doppler in a search mode without seriously lowering the operator's ability to detect a track when it appears. Once the detection is made, more detailed information could be called up from memory storage concerning that specific target situation.

It is intended that topics such as these will be addressed in this portion of the study by use of a combination of analysis and a variety of display devices which are available or are currently under development in the General Electric Company.

E. IMPLEMENTATION TECHNIQUES STUDY

Successful results obtained from these exploratory development studies lead naturally to the question of implementation for the practical case. This study would consider the problems and possibilities of a multiple-beam realization of the system of Figure 3 without getting into the specific design details for any particular application. The various techniques for accomplishing the functions shown in Figure 3 would be outlined and evaluated. By way of example, the filter bank operation would be studied in terms of various FFT approaches and in light of the multiple-beam requirement. The organization of the bulk of the processing functions would be considered relative to the number of central processors and their functions and also the mix of

general-purpose and special-purpose hardware. Methods for implementing the display techniques found to be promising in another portion of the study will be given consideration here. The advisability of making the display devices free-standing peripherals will be evaluated. In addition, the allocation of display logic capability between the main frame of the system and the display sub-systems will be investigated.

F. SUMMARY

The MEDIOR approach to sonar signal processing and display will definitely improve the user's ability to detect, track and classify target data. General Electric has invested considerable effort in this area and is requesting Navy-funded support to refine the techniques into an efficient, cost-effective development program. The program has five measurable areas of activity; each area contributing to the overall system performance improvements as follows:

1) Normalization Study - the objectives include:

   a) Improve the basic (Figure 3) normalization technique by further study of this and associated techniques and the normalization problem in general.

   b) Optimize window and gap size parameters to improve performance.

   c) Obtain quantitive data to determine performance gains in doppler bank outputs when comparing simple vs complex feed-forward techniques.

   d) Optimize performance by investigating statistical differences between different doppler bank outputs.

   e) Investigate adequacy of normalization for the display of multi-beam outputs.

2) Waveform Design Study - the objectives include:

   a) Confirm theoretical advantages of special waveforms.

   b) Optimize system performance during search and track operations by proper selection of transmit waveforms.

   c) Investigate bandwidth as a function of target doppler to optimize performance in mutual interference environment.

   d) Improve performance through optimum use of system transmit time.

3) Doppler Bank Interpolation Study - the objectives include:

   a) Investigate tradeoff between filter bank cost, doppler coverage, and doppler increment.

   b) Minimize filter bank cross-over loss by investigating interpolation techniques for given frequency spacing and filter shapes.

   c) Verify optimization of cross-over loss by simulation on GE 635 computer.

   d) Incorporate improved interpolation technique in brassboard model.

4) Display Techniques Study - the objectives include:

   a) Improve operator threat evaluation effectiveness by investigating man/machine interface for display of multi-beam data.

   b) Investigate tradeoff between sequential display and simultaneous display to increase operator effectiveness with multi-beam data.

   c) Increase operator effectiveness by analyzing effects of false alarm rate, amplitude doppler and range quantization on basic TTRS.

5) Implementation Techniques Study - the objectives include:

   a) Investigate efficient digital techniques for key hybrid processor operations such as represented by the filter bank.

   b) Investigate efficient techniques for multi-beam operation.

SECTION IV
SCHEDULE AND REPORTS

The proposed work covers a six month program. During the program, six monthly letter reports will be issued in addition to a comprehensive final report. The final report will be submitted seven months after date of contract. Two trips to Washington have been budgeted for consultation and presentations.